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Re-skilling Human Resources for Construction 4.0

Implications for Industry, Academia and Government

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Preface

The fourth industrial revolution, also known as Industry 4.0, has transformed the construction industry by creating digital, smart and sustainable construction technologies. The innovative deployment of Industry 4.0 concepts and its application in the construction industry is called Construction 4.0. These new technologies such as Building Information Modelling (BIM), Robotics, 3D printing and Drones give the professionals in the industry a different outlook about optimising their operations to boost the delivery of cost-effective, timely and quality projects. The application of these technologies comes with several benefits and some risks. More importantly, the adoption of these technologies demand new skills for its operation and effective performance.

In order to realise the benefits of these modern technologies, the construction industry needs to address the inevitable challenges, especially those pertaining to human resources. The availability of required skills will improve the implementation of Construction 4.0 technologies. Consequently, it becomes necessary to develop and build talents for the present and future needs of the industry. In line with this, the stakeholders in the industry have roles to play in building the necessary capabilities required to rapidly adapt to the new technologies. The industry is responsible for training the workers, creating a learning environment for practical application of the new technologies and working closely with educational institutions to equip personnel with the required knowledge and skills for Construction 4.0. Also, educational and training institutions with the collaboration of the industry are required to design courses and training programmes that can help nurture, develop and re-skill the human resources suited for a digitalised construction industry.

Furthermore, the governments have a responsibility in policy formulation to reinforce human capital development both at the educational institutions and the workplace. Hence, this research book will examine the key technologies of Construction 4.0, the benefits, risks and relevant skills required to implement the technologies. The book will also consider human resources reskilling needs and the roles of key stakeholders in developing the skills needed for Construction 4.0. This research views the lack of twenty-first century skills and the skills gap, especially in developing countries, as a limiting factor to implementing these technologies.

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Chapter 1
Introduction

1.1 Background to the Study

The construction industry, a significant driver of economic growth of nations, is currently experiencing transformation through advancements in technology ushered by the fourth industrial revolution, also known as Industry 4.0. This transformation is demanding new approaches and specific skills requirements for effective implementation. This revolution is significant as the construction industry represents an economic booster and a major source of employment opportunities. This is also reflected in the 2018 analysis of McKinsey, which reveals that global spending in the construction industry was $11 trillion, with a projection to $814 trillion in 2025, accounting for 9% of World GDP. In sub-Saharan Africa, the construction industry market is projected to register a 6.4% CAGR by the end of 2024 (Africa Review, 2021). An observation of the built environment and humans' daily activities reveals that the construction industry shapes humanity's economic, social, and environmental aspects.

Industry 4.0 is premised on combining physical and digital technologies with data, cyber-physical systems and the Internet of things (IoT) in ensuring smart production and processes. The cyber-physical system, which is the core of the fourth industrial revolution, comprises a pair of technologies that connect the physical and virtual worlds. These technologies can create an intelligent environment where smart objects communicate and interact with one another. The technologies of industry 4.0 include the Internet of Things (IoT), Big Data, Augmented and Virtual Reality, Simulation, cybersecurity, Cloud computing, Robotics, Prefabrication/Additive manufacturing and integration of Horizontal and Vertical systems. These nine (9) pillars have reshaped, reprogrammed and refocused the process, technologies, and methodologies, of many industries, such as the Construction industry. Industries can be assured of operational efficiency, optimised profitability, better quality, increased productivity, customer and stakeholder satisfaction, and more innovations.

Industry 4.0 technologies exert influence and pressure on other industries, especially the construction industry, which is the fulcrum of humanity. The influence of

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industry 4.0 technologies on the construction industry is known as construction 4.0. The construction industry Fourth Industrial Revolution is the application of industry 4.0 in the construction industry (Adepoju & Aigbavboa, 2020). Construction 4.0, according to Sawhney et al. (2020), is "*a paradigm that uses cyber-physical systems, and the internet of things, data and services to link the digital layer consisting of BIM and Common Data Environment (CDE) and the physical layer consisting of the asset over its whole life to create an interconnected environment integrating organisations, process, and information to efficiently design, construct and operate assets*". Construction 4.0, as adapted from industry 4.0 technologies, is the application of emerging technologies, digital processes and cyber-physical procedures to construction activities in the industry. The Fourth industrial revolution in the construction industry is a new dawn of processes driven by digital technologies permeating the architectural, engineering, construction and facility management of the construction industry.

Moreover, construction 4.0 operates on four (4) design principles of interconnection and interoperability, technical assistance (seen in the usage of drones, robots, 3D printing), Information transparency (occasioned by virtual reality and augmented reality in construction processes) and decentralised decision making (Hossain & Nadeem, 2019). Hence, construction 4.0 brings about digital clarity in construction procedures and automated processes in construction activities. The application of Industry 4.0 to Construction can be summarised under six principles which include: virtualisation, decentralisation, modularity, service orientation, interoperability and real-time capability (Hermann, Pentek, & Otto, 2016). Virtualisation is the ability of devices with the use of sensors to monitor physical procedures and communication between machines. The principle of decentralisation entails decentralised decision making empowered through computer systems installed for devices, workers and organisations. Modularity entails establishing a modular manufacturing system, which creates manufactured components that can be assembled, expanded, flexible, and replaced. The principle of service orientation emphasised that the technologies must solve problems and satisfy needs and wants. Interoperability is the ability of technologies to connect, communicate with each other and comprehend the functionality of one another. Real-time capability entails the immediate collection, transmission and analysis of data required by machines and men for effective operations and decision-making processes.

All these principles and models of the fourth industrial revolution have shaped both the construction industry, demanding an adjustment to new ways of building construction projects, new ways of living inside construction projects, and new ways of maintaining finished projects.

1.1.1 Construction 4.0

Construction 4.0 revolves around creating a digital construction site through internet-connected sensors on equipment and its application at modern technologies at every stage of the construction project (Osunsanmi, Aigbavboa & Oke, 2018). This concept has introduced several changes in the construction industry, such as the application of industry 4.0 technologies, mass production, green Construction, increase in professional technological proficiency and customisation. The Construction 4.0 technologies include: Building information modelling (BIM), Big data, Internet of things and services, unmanned aerial vehicle (UAV), additive manufacturing (3D printing), modular prefabricated Construction, 3D scanner, cloud computing, Augmented reality (AR)/ Virtual reality (VR)/ Mixed Reality (MR), simulations of virtual robotics/ autonomous vehicle, GPS, Artificial intelligence, sensors and actuators, cyber-physical systems and Radio-Frequency Identification (RFID) (Kozlovska, Klosova & Strukova, 2021). Most of this technology is infused in the construction industry during application in construction activities. The most prominent Construction 4.0 technologies are Building Information Modeling (BIM), Drones and Unmanned aerial vehicles (UAC), prefabrication, 3D printings, Robotic Construction and the Internet of things. The effective implementation and utilisation of these technologies require specific skills and a technologically oriented environment. However, this book explored six major Construction 4.0 technologies in the construction industry. These are discussed below:

1.1.2 Building Information Modeling (BIM)

The construction industry optimises the construction data and information through building information modelling (BIM). According to Mohandes and Omrany (2013), the BIM is a project simulation technology consisting of three dimensional (3D) models of project components by connecting all the project data and information to the project planning, project constructing and decommissioning. The US National Institute of Building Sciences (2007) defined the BIM as "*a digital representation of physical and functional characteristics of a facility and a shared knowledge resource for information about a facility forming a reliable basis for decision making during its life cycle, defined as existing from earliest conception to demolition*". According to Tahir et al. (2017), the BIM technology applications in the construction industry includes design and visualisation, scheduling, quantity take-off and estimation, quality and risk control, integration and collaboration of stakeholders, clash detection and coordination, analysis of constructability, material resource control, human resource management, facility management, reduction of reworking during Construction, contract administration and efficient communication. The BIM is an integrative technology that collects and use construction stages. Mohandes and Omramy (2013) opined that BIM is very important to the construction industry due to its numerous benefits, such as improvement in project visualisation, proper team management, analysis of complex details, effective project scheduling, estimations of work breakdown structure, quick site preparations, enabling the best routes for pipes, lights, cables, wires, ductwork and sprinklers; proper scheduling for lifts for the utilisation of concrete, steel, electrical equipment placement and huge mechanical equipment placement, evaluation of needed safety precautions and adequate coordination of construction activities. This unequivocally improves construction works, site effectiveness, waste reduction and management, cost-effectiveness and high project performance. The BIM technology is built with various software, including Revit, Revizto, Navisworks, ArchiCAD, Vectorworks Architect, Edificius, Autodesk BIM 360, Sketchup, Buildertrend, BIMobject, Civil 3D, BricsCAD BIM, Sefaria, VisualARQ, AllPlan Architecture, ActCAD BIM (Ocean, 2020).

1.1.3 Drones and Unmanned Aerial Vehicles

Construction works are often complex, depending on the project size or nature of the project site. However, for efficiency, drones which happen to be one of the industry 4.0 technologies, can be utilised. Drones, also known as unmanned aerial vehicles (UAVs) or unmanned aircraft systems (UAS), are like an aircraft without anybody controlled from a remote place. Drones are equipped with downward–facing sensors such as LIDAR, RGB for capturing aerial data in a short time (Wingtra, 2021). Tkac and Mesaros (2019) opined that the utilisation of drones in the construction industry had served many purposes, which includes: inspection of highways, bridges, cell towers, wind turbines, high mast lighting, building façade, surveying and mapping, drainage and erosion, traffic monitoring and wetland. Drone usage in construction 4.0 is mainly for data collection and monitoring purposes. In collecting and collating data from the built environment and construction sites, drones can access and navigates narrow and dangerous locations. The high-quality data collected through drones have helped in construction management in the following areas of site coordination, safety, dispute resolution, quality control, planning and designing documentation of field conditions, the performance of large scale analysis, time management, cost efficiency, aiding better project performance, building surveys, laser scanning and aerial photogrammetric for scanning buildings, thermal image recording for assessing cold spots in buildings (McCoy & Yeganeh, 2021; Tkac & Mesaros, 2019). According to Tkac and Mesaros (2019) and Chapman (2013), different types of Drones are used for construction works, and these include: multi-rotor drones (primarily used for aerial mapping, aerial photography, aerial surveying and video recording); fixed-wing drones, (high altitude drones, used for efficient for aerial mapping topography); single rotor drones (drones with one rotor but last longer in the air than multiple rotors), and fixed-wing hybrid, vertical takeoff and landing rotor (a drone that flies on a pre-scheduled flight route at user-specified heights and collects data through its colour and multispectral sensors).

1.1.4 Prefabrication

Ineffective material management has been a constant headache for construction professionals, as materials are the cornerstones of a construction project. This is why prefabrication technology has been adopted. It entails producing construction components off-sites and then assembled on-site to create/ build the needed structure. According to Li et al. (2014), prefabrication entails producing various construction components at a specialised facility before final assembling and installation. This process is against conventional construction processes of the cast–in–place of concrete, timber formwork, bamboo scaffolding, tilling, reinforcement, and plastering. Auti and Patil (2018) opined that prefabrication technology is the construction process that entails: the finalisation of the design of various components of casting, structure and curing of units, transportation of units on site and the installation of those units. Mays (2021) stated that advantages of prefabricated technology include: a reduction in labour costs, improvement in labour safety, minimisation of construction delays, increase in high quality of work, sminimisation of waste, increases paces of work and increase in energy efficiency.

1.1.5 3D Printing

Another construction 4.0 technology is 3D printing, a digital fabrication technology that produces physical object 3D printing. This digital fabrication technology produces physical objects in a dimensional structure of any shape from a geometrical representation (Shahrubudin, Lee, & Ramlan, 2019). Also, Hossain et al. (2020) stated that 3D (three dimensional) printings, which is industrially known as additive manufacturing, are an automated process that produces 3D shapes using a computer-aided design (CAD) on a layer by layer basis to get the required results. The use of 3D printing technology in the construction industry, which is enhanced by other construction software, is more about the precision of buildings and buildings parts coupled with time effectiveness. Also, in 3D printing, different materials are integrated to print a particular building layer, such as binders, cement, sand, aggregate, and water. 3D printing layers are primarily manufactured and produced off-site before being assembled on the construction site. In the construction industry, the 3D printing technology aids the reduction of a manual process, reduce construction waste by 30–60%, construction time by 50–70%, labour costs by 50–80%, material costs by 65%, and it is environmentally friendly (Markets & Markets, 2020; Hossain et al., 2020; Allouzi, Al-Azhain & Allouzi, 2020). 3D printing is enabled by 3D printers, which includes stereolithography (SLA), selective laser sintering (SLS), fused deposition modelling, FDIM (Formlabs, 2021). Other printers, according to Cherdo (2021), includes; BetAbramPi, COBOD BOD 2, 3D constructor, Cyber construction, ICON Vulcan II, MudBots 3D concrete printer, Total Kustom story Bot 6.2, WASP Crane WASP, APIS cor, Bati print 3D, SQ4D—ARCS, Contour crafting and Xtree E. However, before 3D printings, they are designed in several 3D software, depending on construction requirements. These include Sketch-up, AutoCAD, ArchiCAD, AutoCAD Architecture, DataCAD, Revit, Cedreo, Auto CAD Civil 3D, chief Architect, All plan Vectorworks Architect, Microstation, Bricscad BIM, Rhino 3D, CorelCAD, Solid works (Sculpteo, 2021).

1.1.6 Robotic Construction

Consequently, like most industries, data and information are the operational bedrock of the construction industry. This data feeds into different construction processes and technologies to optimise the satisfaction of end-users and maximise shareholders' wealth.

Moreover, construction activities, processes and procedures require excessive human efforts to achieve project performance, which has led many stakeholders and investors to use automation through Robotics for efficiency and effectiveness. Robotic technology is a technology designed to replace and perfect some human activities and work. Umachandran (2020) stated that Robotics technology is an interdisciplinary field of information engineering, computer science and electro mechatronics to compute and control using sensory feedback and dispensation of data to support applications that substitute human actions. McCoy and Yeganeh (2021) also stated that construction robotics entails the design, construction, operation and application of robots at the different levels of components, building and infrastructure. Turner et al. (2021) opined that Robotics in the construction industry is applied using unmannered aerial vehicles and quadruped robots. Also, robotics is used in various ways, such as surveying construction sites, gathering data for 3D building modelling, and aiding workers in carrying heavy tool kits. Robots, through various computer programming, can be used for painting, bricklaying, loading using an autonomous vehicle without an operator, and acts as technical assistant to construction manager and workers. Robots are both use off-site and onsite, where off-site applications include the production of concrete, brickwork or steel components. In contrast, the onsite applications include reinforcement manufacturing and positioning, steel welding, distribution of concrete, façade operations, earthmoving and material handling (McCoy & Yeganah, 2021). The use of Robots in the construction industry brings about: time efficiency, accessibility and decentralisation of information, aids mobility, improves workers' performance, efficient site management, cost-effectiveness, automation of excavation, drilling, earthworks, precision and accuracy, and increment in productivity. However, there are different kinds and types of robots used in the construction industry, which depends on the task for which it is built. Examples are road bricklaying robots, demolition robots, welding robots, painting robots, humanoid robots, exoskeleton suits robots, forklift robots, contour crafting robots, etc. According to Das (2021), typical robots must exhibit five major fields. The five major fields are: operator interface (a medium of communication between the user and the robots); mobility (that is, it must be able to move, and this is usually designed based on human anatomy), manipulators and effectors (that is the ability of the robots to interact with the environment in moving and picking objects according to commands); programming (this the language inputted into the robots to give commands, allowing it to adapt and learn changes in the environment) and Sensors (the ability of the robot to sense and gather data from the environment using sensors). Robotic technology is a construction 4.0 technology that is bringing about change in the construction industry landscape, construction activities, processes and construction management.

1.1.7 Internet of Things (IoT)

Internet of things is an ecosystem of the Internet, where the Internet is the connector between things and things, people and people and also things and people. Umachandran (2020) stated that IoT technology is an integrated computing device through the attachment of sensors to machines, devices and gadgets for data collection and analysis, situation monitoring and recording. The main backbone technology in the IoT system is Radio Frequency Identification (RFID), which consists of a radio transponder, radio receiver and transmitter to automatically identify and track tags attached to objects, gadgets, machines or equipment.

Moreover, Turner et al. (2021) opined that IoT devices use different communication protocols for sending and transmitting data with different frequencies and ranges. These protocols are; Bluetooth with 2.4 GHz frequency and 50–150 nm; Zig Bee 3.0 protocol of 2.4 GHz within 10–150 m; Wifi of 2.4 GHz and 5 GHz band with approximate 50 m; LoRaWAN of different frequency and between 2 and 15 km and also cellular protocols, with a frequency of 900/1800/1900/2100 MHz and with ranges of 85 km (GSM) and 200kkm (HSPA). Furthermore, McCoy and Yeganeh (2021) stated that the IoT technologies, in collaboration with other technologies in construction 4.0, are applied to: monitor and control the progress of construction projects, identify real-time material and equipment location, monitor workers health, knowledge of the material quantity, observe the conditions of equipment onsite and monitoring of vibration, deformation, tensile stress, comprehensive stress, temperature and wind speed in construction sites.

The technologies of construction 4.0 are efficiency optimisers for the Construction industry, which will help shape all aspects of construction activities. Sawhney et al. (2020) stated that adopting Construction 4.0 technologies in the construction industry would solve productivity stagnancy and low efficiency facing the industry. Also, Turner et al. (2021) opined that construction 4.0 technologies adoption in the industry would lead to efficient utilisation of natural resources, reduced life cycle, costs of construction projects and reduction in greenhouse emission. Qureshi et al. (2020) stated that construction 4.0 would solve the construction industry's long-standing challenges of conflict in scheduling, cost/ budgets overruns and construction risk management. Hossain and Nadeem (2019) opined that the digitalisation of the construction industry would introduce: improvements in construction designs, quality enhancements of construction projects, and efficient digitalisation of the construction industry value chain. Osunsanmi et al. (2018) stated that the adoption of Construction 4.0 technologies would have the following advantages: the creation of a sustainable building, speedy budget project delivery, enhancement of safety, facilitation of harmonious relationship between professionals, adequate construction planning, effective monitoring and controlling, encourage seamless communication throughout the organisation, promotes the participation of employees in the decision making process, reduction of errors and rework, and overall ensure client satisfaction. Unequivocally, the adoption and usage of Construction, 4.0 technologies in the construction industry and the built environment will lead to: a sustainable environment, high rate of project success, cost-effective construction projects, minimisation of waste, improvement in safety management, assurance of quality at all stages of construction, enhanced time performance and schedule, aid more innovations breakthrough in the industry, improved workers productivity, increase the life cycle value of buildings and construction projects, effective data management and analytics, helps in the attainment of the United Nation 2030 sustainable development goals and increase construction industry contribution to a nation's economic growth and development.

1.1.8 The Need for Reskilling and Upskilling

However, the benefits, importance, features, and advantages of Construction 4.0 technologies adoption in the construction industry have placed an enormous demand on skill development in the industry since the industry is an epochal transition. Adepoju and Aigbavboa (2021) and Alaloul et al. (2019) stated that these technologies would lead to skill disruptions altering skills, practices and approaches in the construction industry. Also, this disruption will lead to the loss of thousands of jobs, as the technologies of construction 4.0 will replace human labour. According to Adepoju and Aigbavboa (2020), the digitalisation of construction work comes with several benefits and opportunities despite its challenges, such as the loss of jobs. The benefits and opportunities identified are: advancements in productivity of employees, promotion of job satisfaction among workers, reduction in construction risks for workers, reduction in the number of hours required for a worker, reduction in accidents and loss of lives, workers access to current project information and team management.

Nevertheless, the challenges and opportunities ushered by construction 4.0 technologies are a research gap in skill development in upskilling and re-skilling in the construction industry, which is the book's focus. Slowey et al. (2019) and Cerika and Maksumic (2017) also emphasised the opportunity of skill acquisition and development in creating a skilful, better and creative workforce for the industry. Also, Ras et al. (2017) opined that technology usage in industry 4.0 would lead to a shift and upgrade of job profiles, which might be challenging since most needed skills are more interdisciplinary. Manda and Backhouse (2017) stated that the new technologies in the industry require a new breed of innovative and technologically savvy workers.

Vuyiswa and Nischolan (2019) noted that the new required skills would include: analytical thinking and innovation; active learning and learning strategies; creativity, originality and initiative; technology design and programming; critical thinking and analysis; complex problem solving; leadership and social influence; emotional intelligence; reasoning, problem-solving and creativity; and system analysis and evaluation. According to a McKinsey report, more than 371 Million workers might need to change their levels and type of skills by the year 2030 due to the digitalisation of various industries (Chakma & Chaijinda, 2020). The required skills are technical and soft skills for utilising each of the technologies in the industry, which will lead to a wide skill gap in the construction industry. Adepoju & Aigbavboa (2021) averred that the skill gap entails the differences in the current level of skills in an organisation or industry and the future skills needs of the organisation. This is currently happening in the construction industry before the advent of construction 4.0, where employers cannot find the required work with the right skill in the labour market even in developed and developing countries (Juricic, Galic & Marenjak, 2021). However, in bridging this skill gap created by construction 4.0, there is a need for re-skilling and upskilling, which construction stakeholders and professionals must support across the industry.

According to Sivalingam & Manson (2020), re-skilling means learning an entirely new skill which leads to a new job profile and career position while upskilling is learning new skills that will improve the current job profile. Also, as stated in Chakma and Chaijinda (2020), the, Cambridge dictionary describes re-skilling as an attempt made "*to learn new skills so that you can do different jobs*" and upskilling means "*to learn new skills or to teach workers new skills*". Therefore, with construction 4.0 technologies in the construction industry, construction workers and professionals must adapt quickly to the mechanism of upskilling and re-skilling of skills in the industry to match the expected Construction 4.0 technical and soft skills. This is necessary to avert the loss of an experienced and knowledgeable construction workforce.

Consequently, in re-skilling and upskilling of skills in the construction industry in line with construction 4.0 technology, there is need for a collaborative though separated efforts of construction industry stakeholders, including the industry, academia and the government, in the form of a skilled supply chain. Through various construction companies, the industry must begin to see re-skilling and upskilling of their workforce (through training and retraining) as an investment into organisational growth and sustainability. Construction companies must start to give skill training a priority by ensuring their professionals and workers attend required courses, conferences, symposiums, and events that will re-skill and upskill them in line with the skills needed for construction 4.0. Also, construction companies should adopt the mechanism of interdepartmental and Intra–organisational partnership for appropriate knowledge and skill transfer, thus helping them in re-skilling and upskilling their workforce. However, as the industry through construction companies and bodies shapes the current workforce in line with construction 4.0 required skills, academia has a two-way approach to help in re-skilling and upskilling in the construction industry. Firstly, academia must rejig curriculum in the built environment to suit